Ares I Scale Model Acoustic Test Instrumentation for Acoustic and Pressure Measurements

Acoustical Society of America
162nd Meeting Session 4pNS
Noise and Physical Acoustics: Launch Vehicle Noise II
November 3, 2011

Magda B. Vargas
All Points Logistics/ESTS Group
Douglas Counter
NASA Marshall Space Flight Center

JACOBS
ESTS Group

Agenda

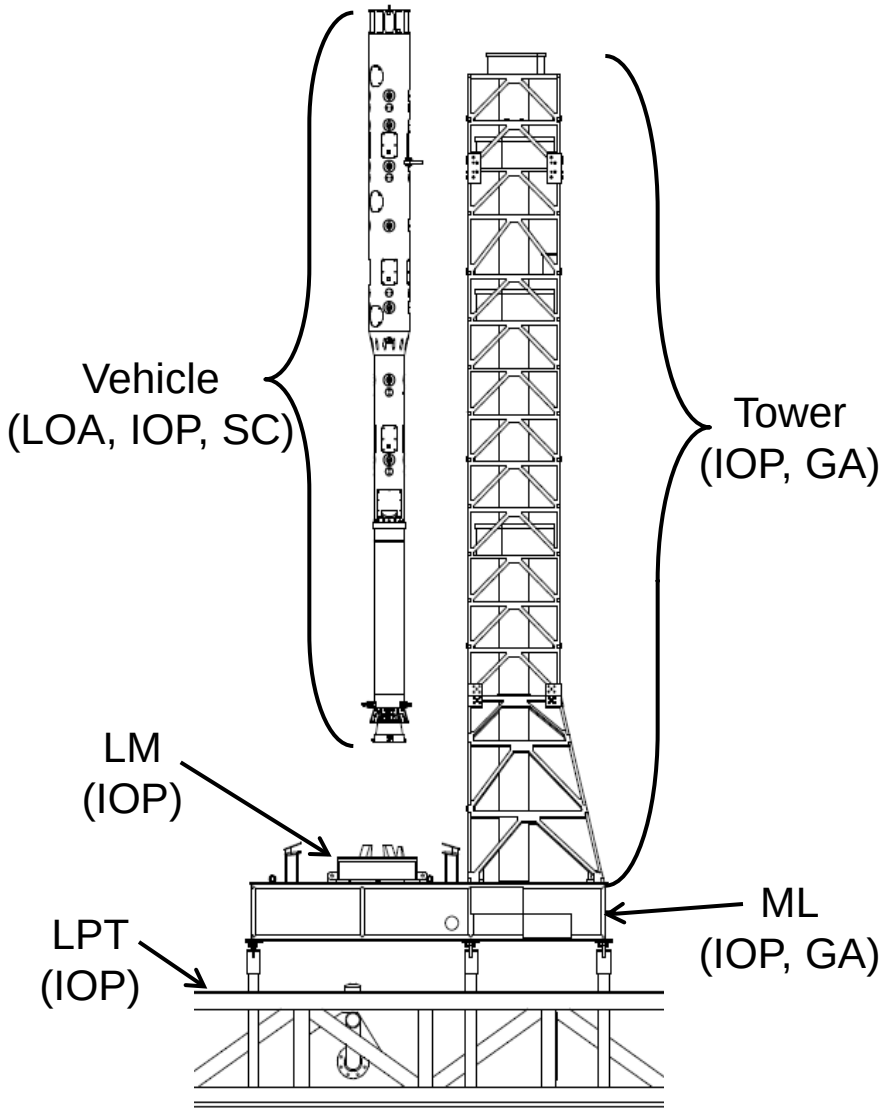
- Overview and Scope
- Sensors
- Sensor Effects
- Mounts
- Mount Effects
- Conclusions
- Backup

Overview and Scope

- Ares I Scale Model Acoustic Test (ASMAT) is a 5% scale model test of the Ares I vehicle, launch pad and support structures conducted at MSFC to verify acoustic and ignition environments and evaluate water suppression systems
- Test design considerations
  - 5% measurements must be scaled to full scale requiring high frequency measurements
  - Users had different frequencies of interest
    - Acoustics: 200 - 2,000 Hz full scale equals 4,000 - 40,000 Hz model scale
    - Ignition Transient: 0 - 100 Hz full scale equals 0 - 2,000 Hz model scale
  - Environment exposure
    - Weather exposure: heat, humidity, thunderstorms, rain, cold and snow
    - Test environments: Plume impingement heat and pressure, and water deluge impingement
- Several types of sensors were used to measure the environments
- Different instrument mounts were used according to the location and exposure to the environment
- This presentation addresses the observed effects of the selected sensors and mount design on the acoustic and pressure measurements

Overview and Scope

- 5% ASMAT model includes
  - Vehicle
  - Tower
  - Mobile Launcher (ML)
  - Launch Mount (LM)
  - Launch Pad Trench (LPT)
- ASMAT measurements included
  - Liftoff Acoustics (LOA):
    4,000-40,000 Hz
  - Ignition Overpressure (IOP) and transient wave: 0- 2,000 Hz (10,000 Hz for CFD)
  - Ground Acoustics (GA):
    4,000-40,000 Hz
  - Spatial Correlations (SC):
    4,000-40,000 Hz



Sensors

- A combination of microphones and pressure sensors were used throughout the model to measure the environments
  - Microphone
    - B&K 4944B – LOA and GA
  - Pressure Transducers
    - Kulite XTL 123B-190-30 SG and -65 SG – IOP
    - PCB 122A22 - GA
    - Kulite XCEL-12-100-2D - SC

B&K 4944


PCB 112

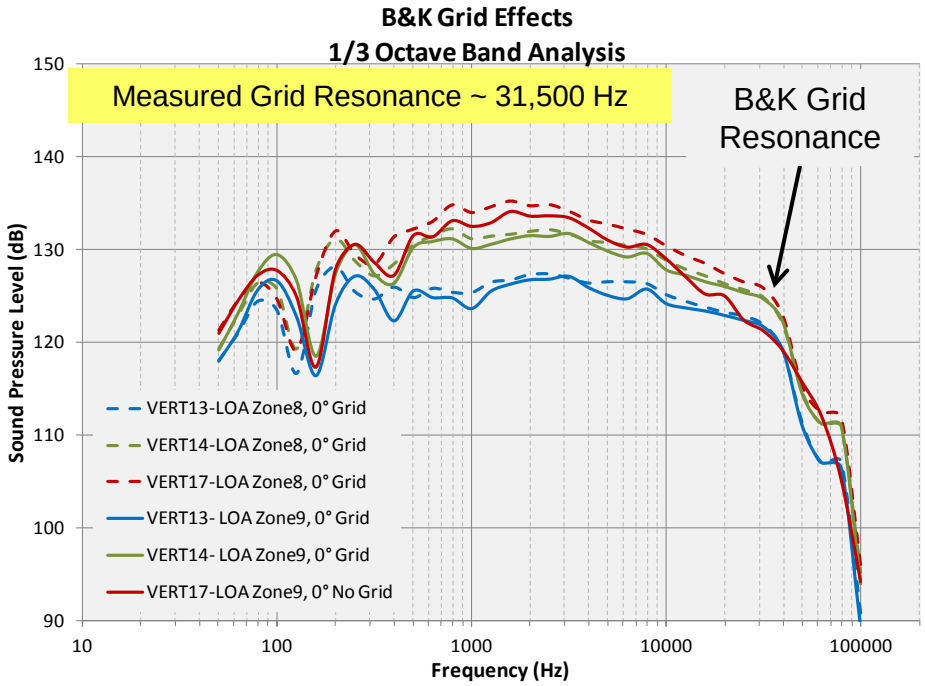

Kulite XTL-123


Kulite XCEL-100

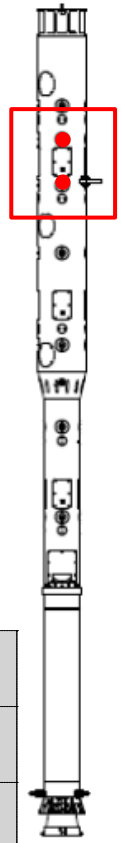
Sensor Effects

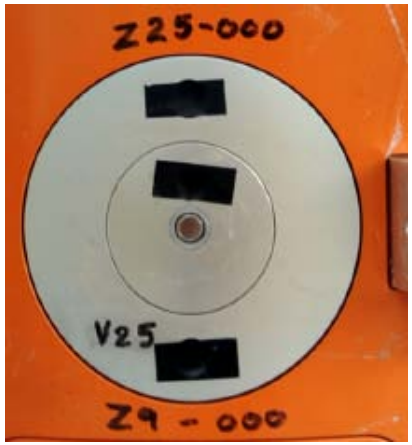
- Each instrument used has a diaphragm resonant frequency above the frequency of interest
  - B&K 4944B – 60 KHz
  - Kulite XTEL-123B-190 – 175 kHz
  - PCB 112A22 – ≥250 kHz
  - Kulite XCEL-12-100-2D – ≥150kHz
- Protective screens introduced additional resonances
  - B&K 4944B – 31.5 kHz peak
  - Kulite XTEL-123B-190 - 41kHz peak

Sensor Effects – B&K Grid



LOA Microphone - Grid

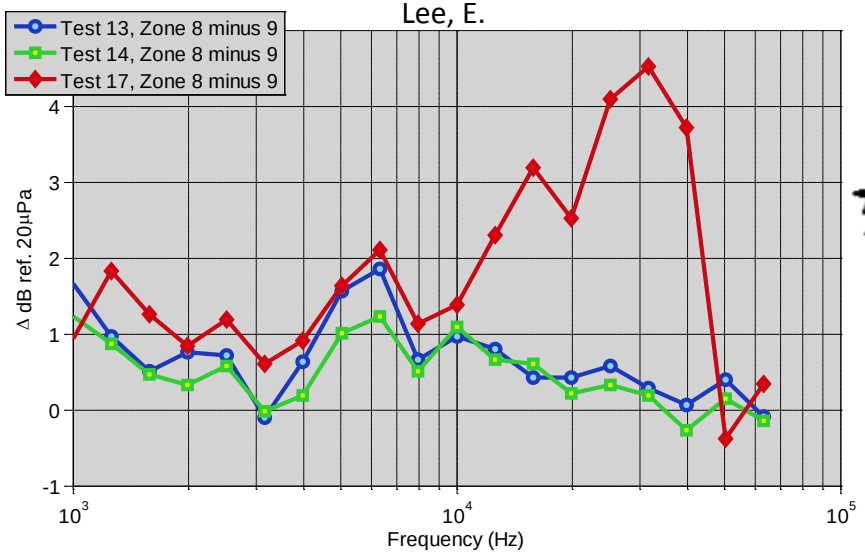




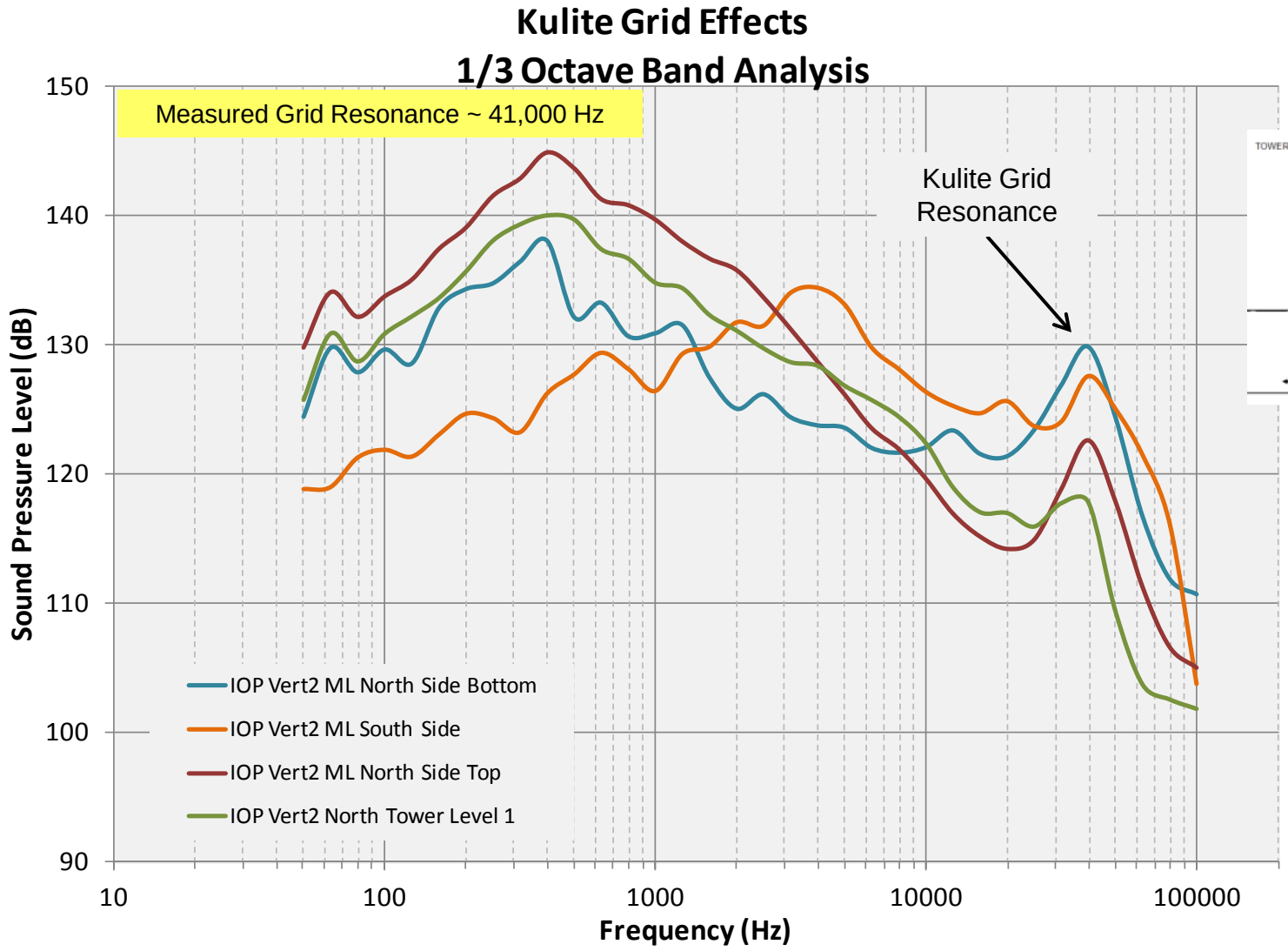
LOA Microphone - No Grid

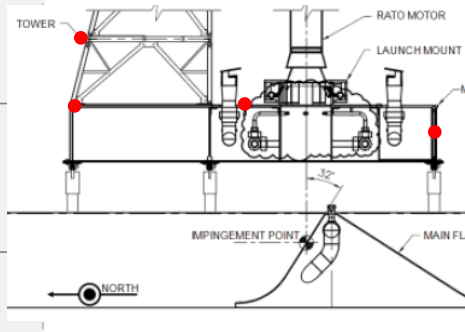
ASMAT_gridAssesment.fig

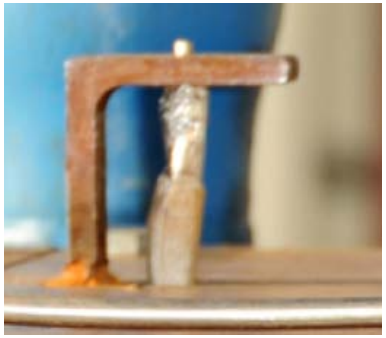
Lee, E.



Sensor Effects – Kulite Grid







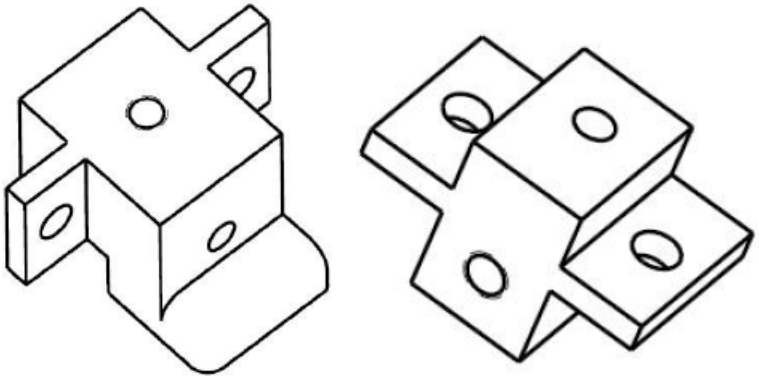
Mounts

- Instrument mounts were designed according to the model location

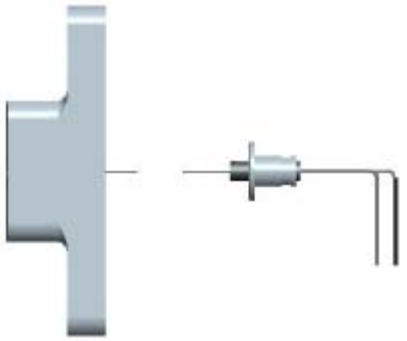
LOA Vehicle Mount (Diaphragm Flushed)

GA Tower Mount (Flushed) and IOP North Tower Mount (Protruding)

IOP Vehicle Mount (Cavity)



IOP ML Mount (Tube)

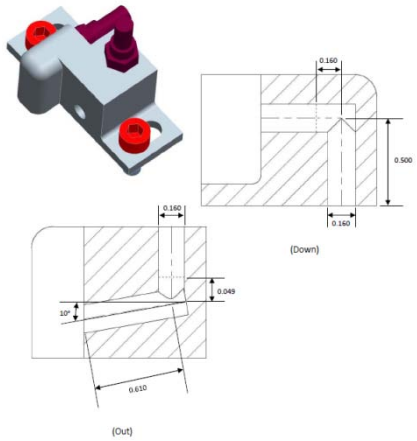


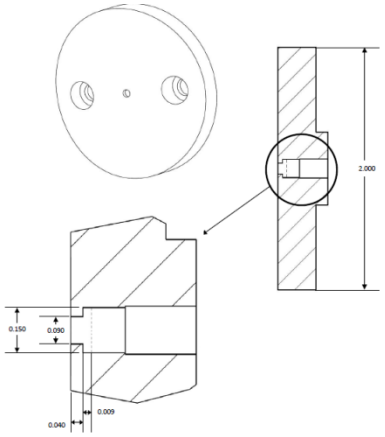
SC Vehicle Mount (Cavity)

JACOBS ESTS Group

Mounting Effects

- Some of these mounts introduced either cavity or tube resonances in the measurements
  - Calculated Tube Resonances
    - IOP: South Side Tower Blocks - ~4,500 Hz
    - IOP: Mobile Launcher Underside Blocks - ~5,000 – 5,500 Hz
    - IOP: Launch Mount Blocks – 3,300 – 6,300 Hz
    - IOP: Launch Pad Trench Blocks - ~ 5,100 Hz
    - IOP: Exhaust Hole Blocks - ~5,000 – 5,500 Hz
    - GA*: 1/8” Recessed - ~14,300 Hz
  - Calculated Cavity Resonances
    - IOP: Vehicle Mounts - ~27,500 – 29,200 Hz
    - GA**: Covers - ~9,300 Hz
    - SC: All Mounts - ~22,300



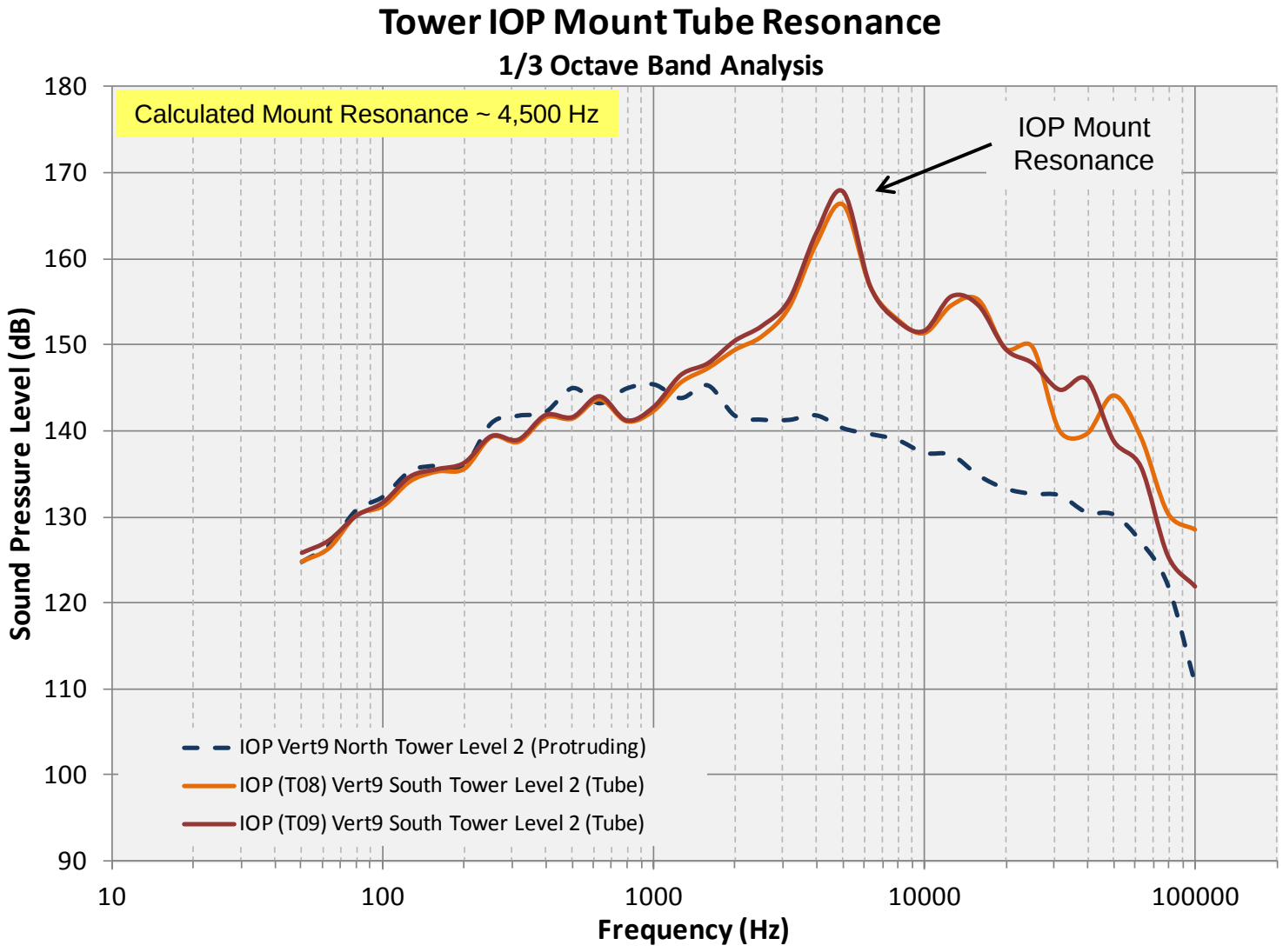


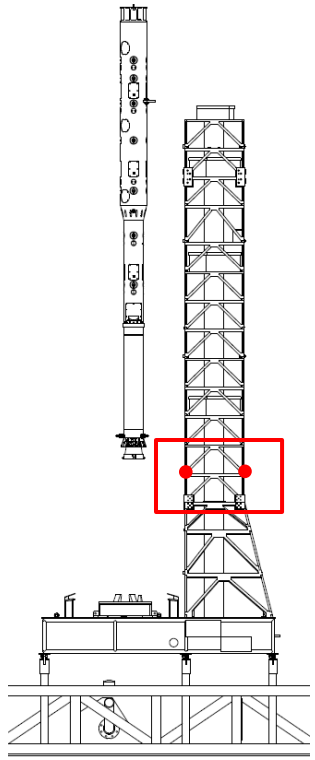
Note:

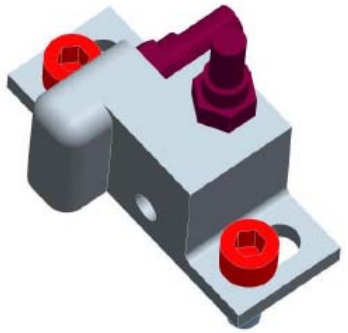
*GA 1/8” Recessed only during Vert9 South Side Tower Level 1 and 2 except for G02 and G07 which were flushed

**GA Covers only for Vert7 G02 and Vert8 South Side Tower Level 1 and 2

Mounting Effects – IOP Tube

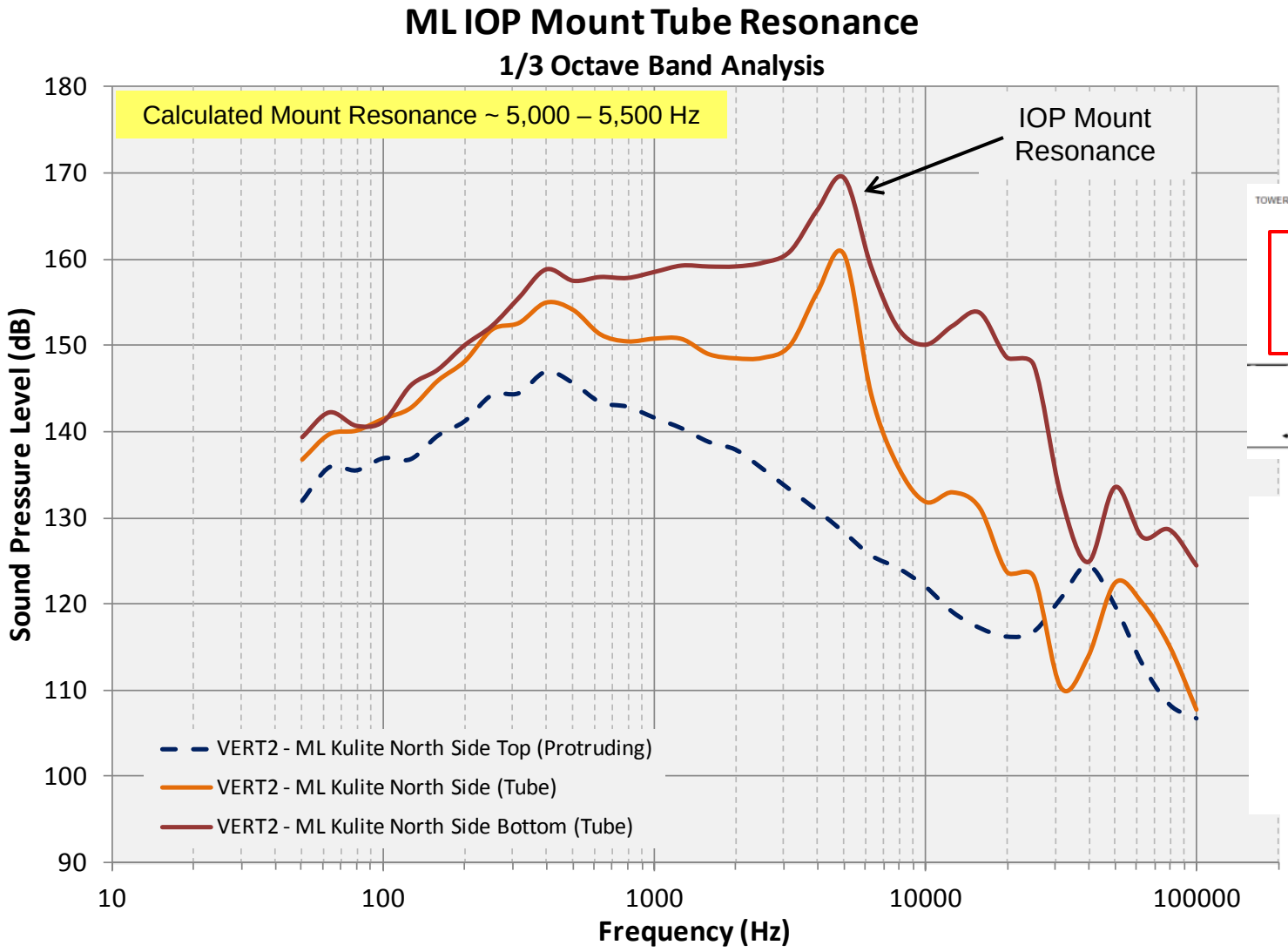


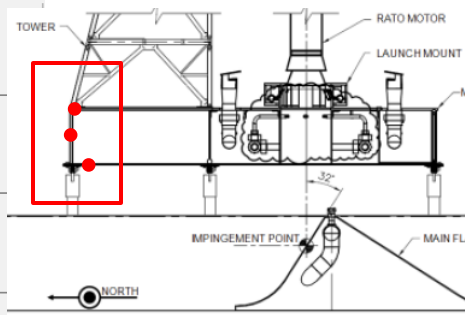


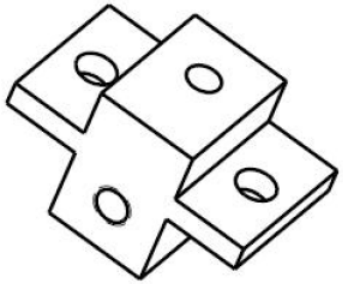


JACOBS ESTS Group

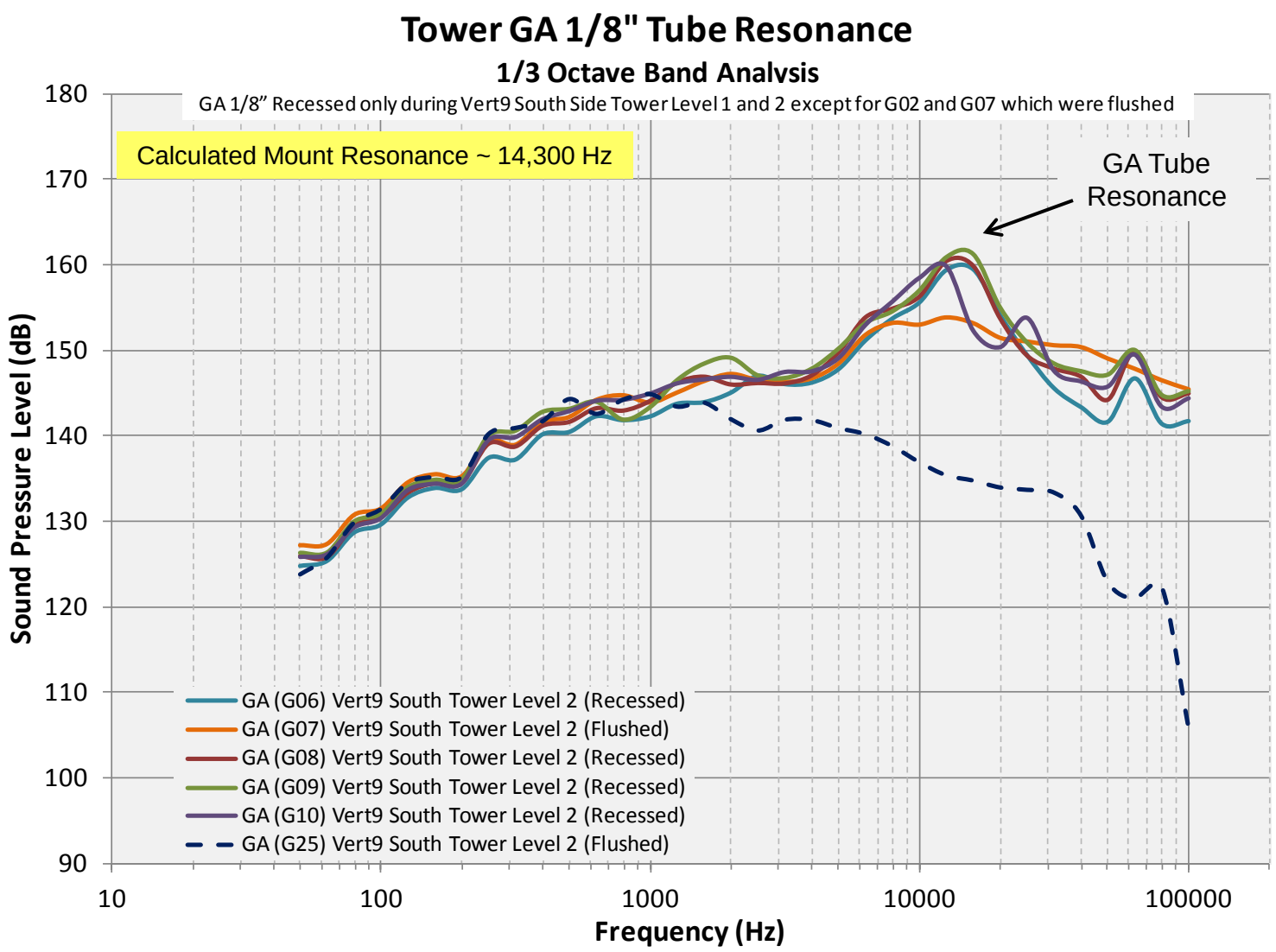
Mounting Effects – IOP Tube

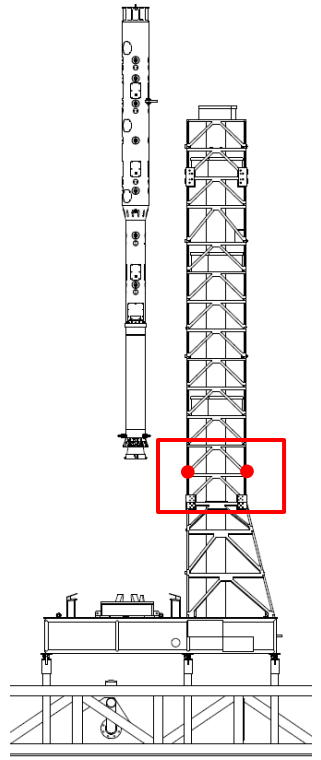




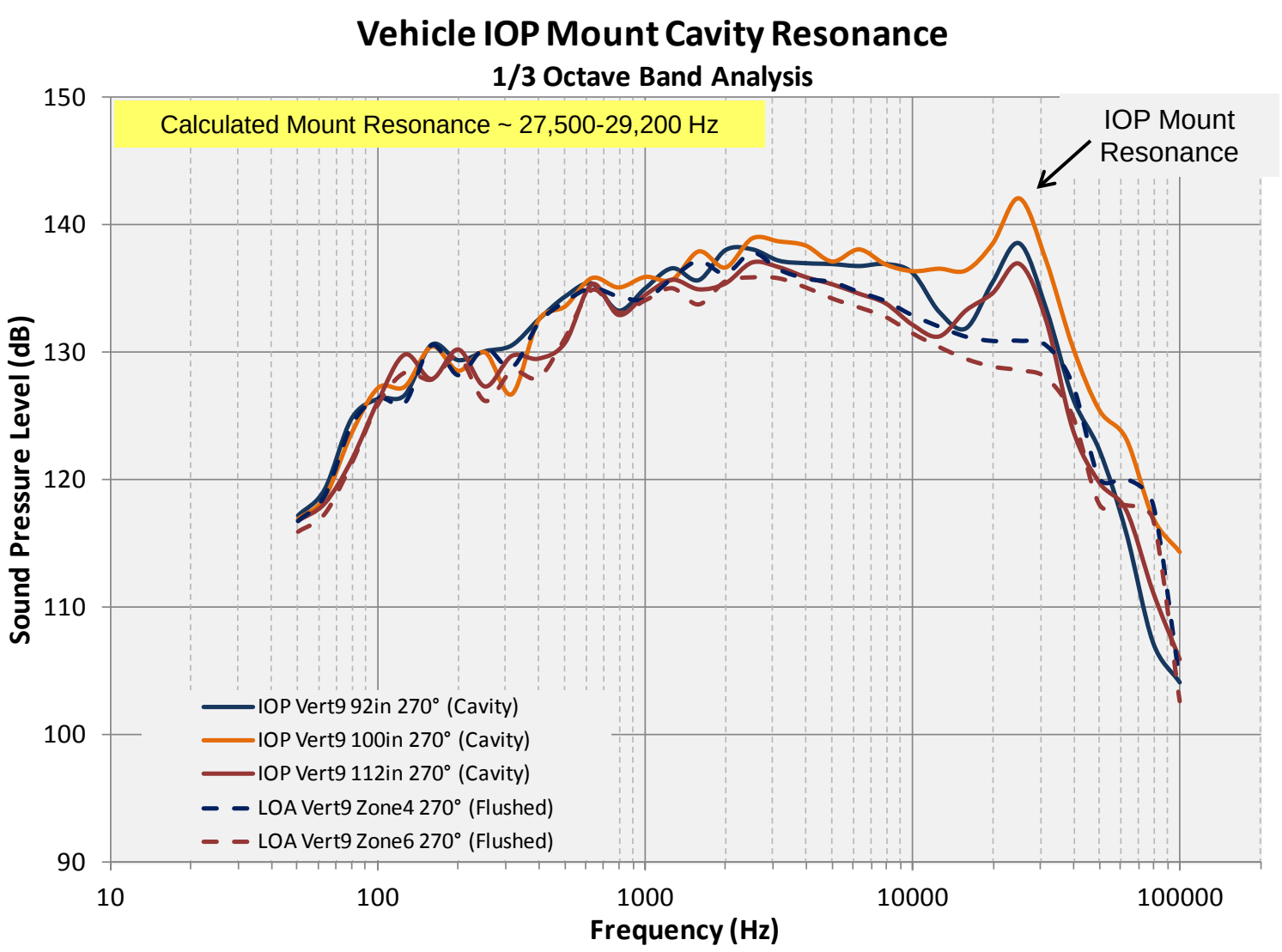


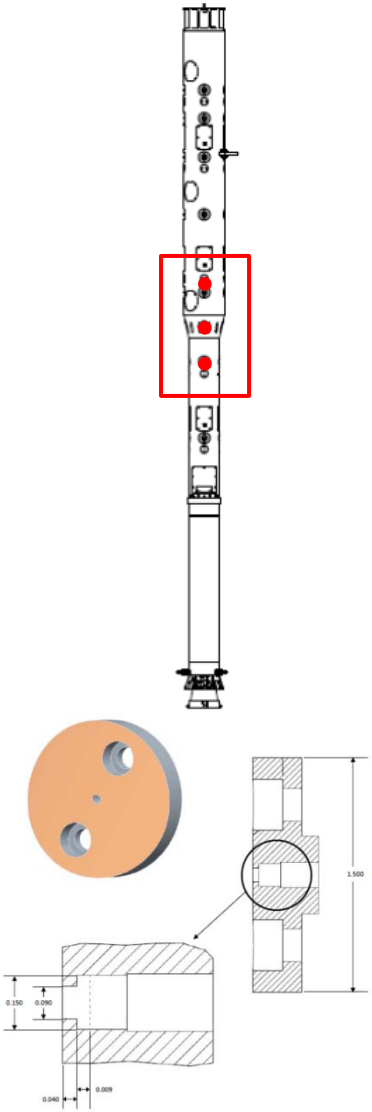
Mounting Effects – GA Tube



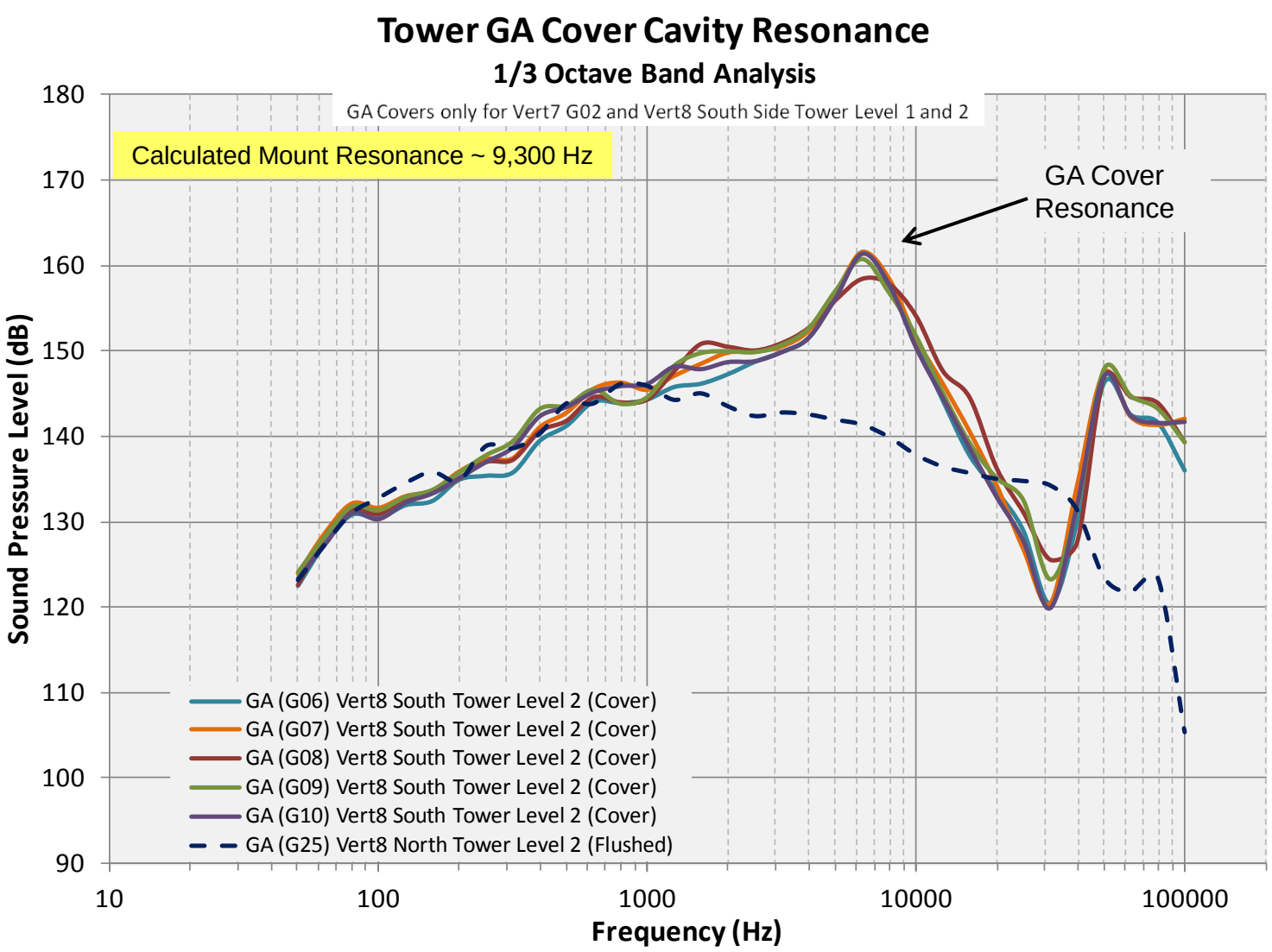


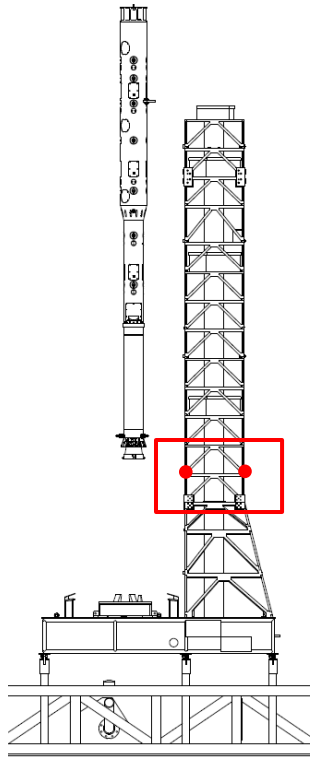
Mounting Effects – IOP Cavity



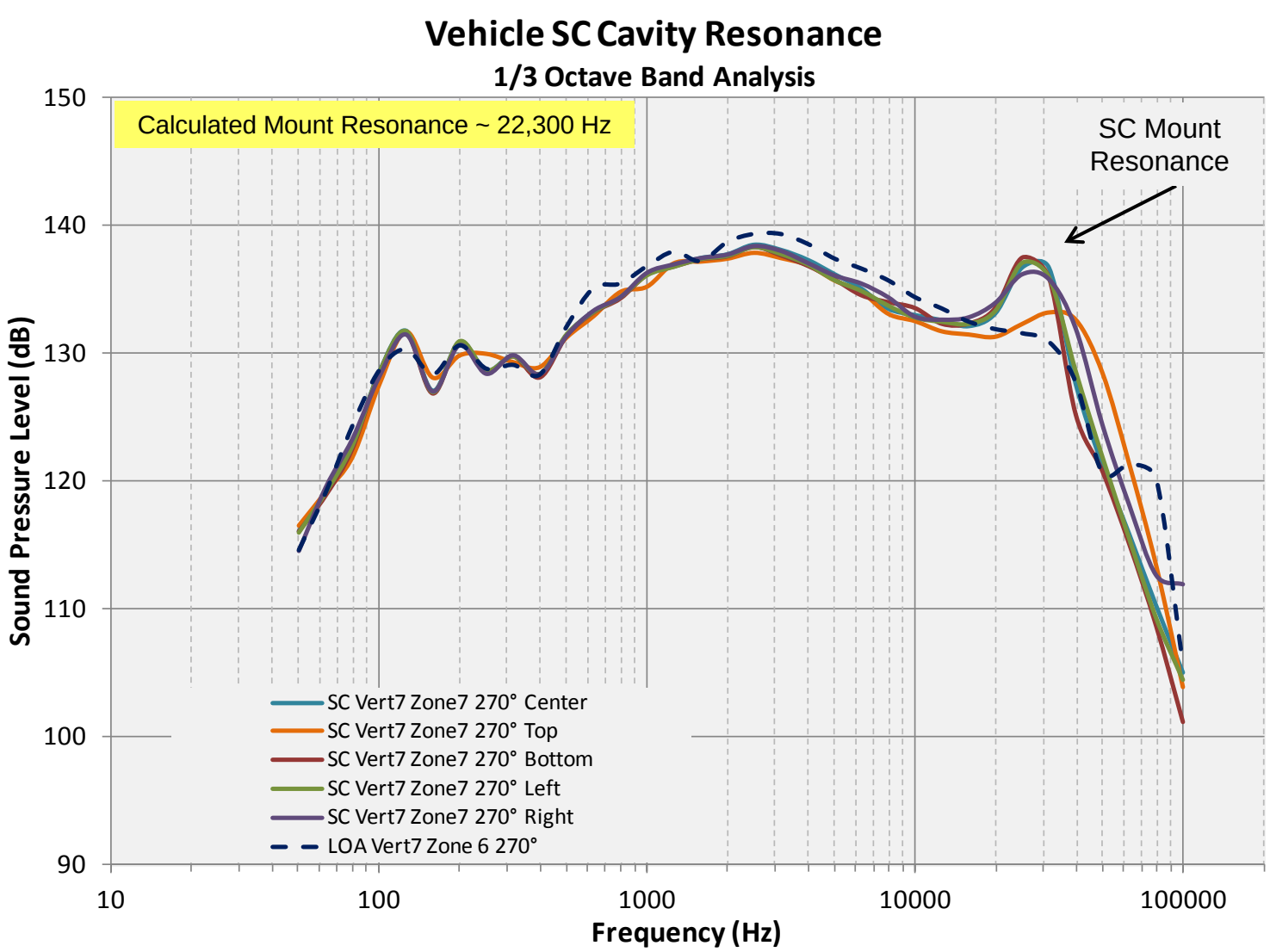


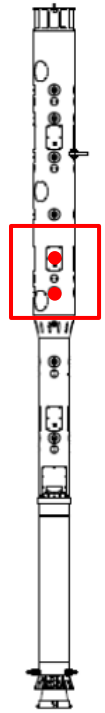
Mounting Effects – GA Cavity





Mounting Effects – SC Cavity





Conclusions

- Appropriate sensors were selected for the measurements
  - IOP Kulite grid and mount resonances occurred beyond the frequency range of interest.
  - LOA measurements will be corrected to remove the grid resonance.
  - GA and SC sensor resonances beyond the frequencies of interest .
- Proper mount design
  - Mount induced resonances occur beyond the user's frequency of interest.
  - The mounting measures used during the ASMAT program protected most of the sensors exposed to the plume environments and resulted in low sensor loss.
  - Attempts to protect the GA sensors from the plume environments resulted in mount induced resonances that limited the frequency range of useful data.
- The measured and calculated resonances agree; the data can be corrected for both grid and mount induced resonances.

Questions

Backup

- Resonance Equations
- Data Acquisition Parameters
- Data Processing Parameters
- Sensor Spec Sheets

Resonance Equations

- Tube Resonance

$$f = \frac{c}{4(L + 0.4D)}$$

c = speed of sound (in/sec)

L = tube length (in)

D = tube diameter (in)

- Cavity Resonance

$$f = \frac{c}{2\pi}\sqrt{\frac{S}{(L + 0.4D)V}}$$

c = speed of sound (in/sec)

S = neck area (in^2)

L = neck length (in)

D = neck diameter (in)

V = chamber volume (in^3)

Data Acquisition Parameters

- Coupling
  - DC - IOP and SC measurements
  - AC – LOA and GA measurements
- Sample Rates
  - 4000 sps – IOP
  - 256000 sps – LOA, IOP, GA and SC
- Data converted and delivered in engineering units
  - IOP and SC – psi
  - LOA and GA - Pa

Data Processing Parameters

- DC component removed during post processing
- Processing parameters selected according to sample rate in order to keep a consistent number of blocks
  - 256,000 sps
    - Time Domain
      - Time Window: -0.5 – 4.492 seconds
      - Reduction Time: 0.032 seconds
    - Frequency Domain
      - 1/3 Octave Band Range (Center Frequency): 50 – 128,000 Hz
      - Frequency Resolution: 1.953 Hz
      - Fast Fourier Transform Block Size: 131,072 samples
      - Frequency Analysis Time Window: 0.5 – 2.036
      - Window Type: Rectangular
      - Reference Pressure
        - 2.9×10^{-9} for measurements in psi
        - 2×10^{-5} for measurements in Pa
      - N Average: 3

Sensor Spec

PRODUCT DATA

¼″ DeltaTron® Pressure-field Microphones — Types 4944-A and 4944-B

Types 4944-A and 4944-B are ¼″ Prepolarized Pressure-field Microphones laser welded to ¼″ DeltaTron preamplifiers.

The preamplifier connects to CCLD input conditioning and supports IEEE P1451.4 V 0.9 TEDS (Transducer Electronic Data Sheet).

USES
- High-level measurements
- High-frequency measurements
- Flush mounting

FEATURES
- Sensitivity: 0.9 mV/Pa
- Frequency: 16 – 70 000 Hz
- Dynamic Range: 48 dB(A) – 169 dB
- Temperature: –20 to +100°C (–4 to +212°F)
- TEDS: IEEE P1451.4
- SMB or 10 – 32 UNF socket
- Connects to CCLD input

Description

Uses of Types 4944-A and 4944-B
A pressure-field microphone is designed to be used in small closed couplers, close to hard reflective surfaces or flush-mounted. The sensitivity has been optimised to allow measurements of high sound pressure levels without clipping in the built-in DeltaTron preamplifier.

Design and Robustness
The shape of the microphone front ensures excellent microphone performance when flush-mounted. The laser-welded diaphragm on the microphone housing ensures that the sensitivity is resistant to rough handling during flush mounting.

Microphone Data CD
The microphone is supplied with a mini-CD. This mini-CD carries all individual calibration data as well as random-incidence and free-field corrections. The influence of ¼″ Nose Cone UA-0385 is also available.

Calibration
The sensitivity can be calibrated at 250 Hz using Pistonphone Type 4228 with ¼″ Adaptor DP-0775. The pressure-field response can be measured using Actuator UA-0033 with Adaptor DB-0264. The pressure-field response is equal to the actuator response.

Brüel & Kjær

JACOBS ESTS Group

Data Processing Parameters

Model Number 112A22	PRESSURE SENSOR, ICP®	Revision G ECN #: 30161

Performance	ENGLISH	SI	
Measurement Range (for ±5V output)	50 psi	345 kPa	
Useful Overrange (for ± 10V output)	100 psi	690 kPa	[1]
Sensitivity (±15 %)	100 mV/psi	14.5 mV/kPa	
Maximum Pressure	500 psi	3450 kPa	
Resolution	1 mpsi	0.007 kPa	
Resonant Frequency	≥250 kHz	≥250 kHz	
Rise Time	≤2.0 µ sec	≤2.0 µ sec	
Low Frequency Response (-5 %)	0.50 Hz	0.50 Hz	
Non-Linearity	≤1.0 % FS	≤1.0 % FS	[2]
Environmental			
Acceleration Sensitivity	≤0.002 psi/g	≤0.0014 kPa/(m/s²)	
Temperature Range (Operating)	-100 to +275 °F	-73 to +135 °C	
Temperature Coefficient of Sensitivity	≤0.06 %/°F	≤0.108 %/°C	
Maximum Flash Temperature	3000 °F	1650 °C	
Maximum Shock	20000 g pk	196000 m/s² pk	
Electrical			
Output Polarity (Positive Pressure)	Positive	Positive	
Discharge Time Constant (at room temp)	≥1.0 sec	≥1.0 sec	
Excitation Voltage	22 to 30 VDC	22 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	<100 ohm	<100 ohm	
Output Bias Voltage	8 to 14 VDC	8 to 14 VDC	
Physical			
Sensing Geometry	Compression	Compression	
Sensing Element	Quartz	Quartz	
Housing Material	17-4 Stainless Steel	17-4 Stainless Steel	
Diaphragm	Invar	Invar	
Sealing	Welded Hermetic	Welded Hermetic	
Electrical Connector	10-32 Coaxial Jack	10-32 Coaxial Jack	
Weight (with clamp nut)	0.21 oz	6.0 gm	

CE[3]

All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.
ICP® is a registered trademark of PCB group, Inc.

Optional Versions (Optional versions have identical specifications and accessories as listed for standard model except where noted below. More than one option maybe used.)

E - Emralon coating			[4]
Coating	Emralon	Emralon	
Electrical Isolation	10^8 ohm	10^8 ohm	
Supplied Accessory: Model 065A08 Isolation ring, 0.250" OD x 0.218" ID x 0.027" thk, anodized aluminum			
Supplied Accessory: Model 065A22 Isolation Seal, .250" OD x .218" ID x .015", Torlon or Vespel			
H - Hermetic Seal			[4]
Sealing	Welded Hermetic	Welded Hermetic	
J - Ground Isolated			[4] [5]
N - Negative Output Polarity			[4]
S - Stainless Steel Diaphragm			[4]
Diaphragm	316L Stainless Steel	316L Stainless Steel	
W - Water Resistant Cable			[4]
Supplied Accessory: Model 060A03 Clamp nut, 5/16-24-2A thd, 1/4" hex, stainless steel (for Series 111, 112 and 113)			[4] [6]
WM - Water Resistant Cable			[4]
Supplied Accessory: Model 060A05 Clamp nut, M7 x 0.75-6G thd (for Series M111, M112 and M113)			[4] [6]

Notes
[1] For +10 volt output, minimum 24 VDC supply voltage required. Negative 10 volt output may be limited by output bias.
[2] Zero-based, least-squares, straight line method.
[3] See PCB Declaration of Conformance PS023 for details.
[4] For sensor mounted in thread adaptor, see adaptor installation drawing for supplied accessories.
[5] Used with optional mounting adaptor.
[6] Clamp nut installed prior to cable attachment

Supplied Accessories
060A03 Clamp nut, 5/16-24-2A thd, 1/4" hex, stainless steel (1)
060A05 Clamp nut M7 x 0.75-6g thd (1)
065A02 Seal ring, sensor flush mount, 0.248" OD x 0.219" ID x 0.015" thk, brass (3)
065A05 Seal sleeve sensor recess mount 0.248" OD x 0.221" ID x 0.240" thk 17-7 (1)

Entered: BLS	Engineer: NJL	Sales: RWM	Approved: EB	Spec Number:
Date: 02/24/2009	Date: 02/13/2009	Date: 02/24/2009	Date: 02/23/2009	6476

PCB PIEZOTRONICS PRESSURE DIVISION
3425 Walden Avenue
Depew, NY 14043
UNITED STATES
Phone: 888-684-0011
Fax: 716-686-9129
E-mail: pressure@pcb.com
Web site: www.pcb.com

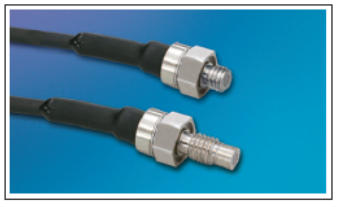
Data Processing Parameters

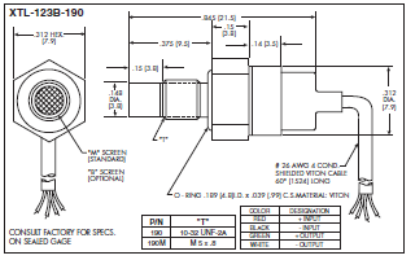
kulite

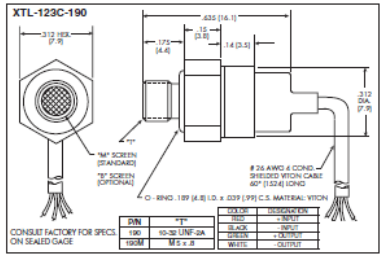
RUGGEDIZED AUTOMOTIVE IS®
PRESSURE TRANSDUCERS

XTL-123B-190 (M) SERIES XTL-123C-190 (M) SERIES

- Easy Installation
- High Natural Frequency
- 10-32 UNF or M 5 x .8 Thread
- Wide Temperature Range
- Compatible With All Automotive Fluids
- Intrinsically Safe Patented Leadless Technology Applications Available (i.e. IS-XTL-123B-190 or IS-XTL-123C-190)







INPUT Pressure Range	1.0 15	1.7 25	3.5 50	7 100	17 250	35 500	70 1000	100 1500	210 BAR 3000 PSI
Operational Mode	Absolute, Sealed Gage, Gage, Differential					Absolute, Sealed Gage			
Over Pressure	2 Times Rated Pressure to a Maximum of 4500 PSI (315 BAR)								
Burst Pressure	3 Times Rated Pressure to a Maximum of 4500 PSI (315 BAR)								
Pressure Media	All Nonconductive, Noncorrosive Liquids or Gases (Most Conductive Liquids and Gases - Please Consult Factory)								
Rated Electrical Excitation	10 VDC								
Maximum Electrical Excitation	15 VDC								
Input Impedance	1000 Ohms (Min.), 5000 Ohms (Max.)								
OUTPUT Output Impedance	1000 ± 500 Ohms								
Full Scale Output (FSO)	100 mV ± 10 mV								
Residual Unbalance	± 5mV (Typ.)								
Combined Non-Linearity, Hysteresis and Repeatability	± 0.1% FSO BFSL (Typ.), ± 0.5% FSO (Max.)								
Resolution	Infinitesimal								
Natural Frequency (KHz) (Typ.)	Greater Than 175 KHz								
Acceleration Sensitivity % FS/g Perpendicular Transverse	$6.5x10^{-4}$ $1.0x10^{-4}$	$5.0x10^{-4}$ $6.0x10^{-4}$	$3.0x10^{-4}$ $4.0x10^{-4}$	$1.5x10^{-4}$ $2.0x10^{-4}$	$1.0x10^{-4}$ $9.0x10^{-5}$	$6.0x10^{-5}$ $6.0x10^{-5}$	$4.5x10^{-5}$ $3.0x10^{-5}$	$3.5x10^{-5}$ $2.7x10^{-5}$	$2.0x10^{-5}$ $2.0x10^{-5}$
Insulation Resistance	100 Megohm Min. @ 50 VDC								
ENVIRONMENTAL Operating Temperature Range	-65°F to +400°F (-55°C to +204°C)								
Compensated Temperature Range	-40°F to +350°F (-40°C to +175°C)								
Thermal Zero Shift	± 1% FS/100°F (Typ.)								
Thermal Sensitivity Shift	± 1% /100°F (Typ.)								
Linear Vibration	100g Peak, Sine Up to 5000 Hz								
Humidity	100% Relative Humidity								
Mechanical Shock	100g half Sine Wave 11 msec. Duration								
PHYSICAL Electrical Connection	4 Conductor 26 AWG Shielded Viton Cable 60" Long								
Weight	5 Grams (Nom.) Excluding Cable								
Pressure Sensing Principle	Fully Active Four Arm Wheatstone Bridge Dielectrically Isolated Silicon on Silicon Patented Leadless Technology								
Mounting Torque	15 Inch-Pounds								

Note: Custom pressure ranges, accuracies and mechanical configurations available. Dimensions are in inches. Dimensions in parenthesis are in millimeters. Continuous development and refinement of our products may result in specification changes without notice - all dimensions nominal. (F)

KULITE SEMICONDUCTOR PRODUCTS, INC. • One Willow Tree Road • Leonia, New Jersey 07605 • Tel: 201 461-0900 • Fax: 201 461-0990 • http://www.kulite.com

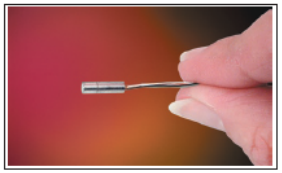
Data Processing Parameters

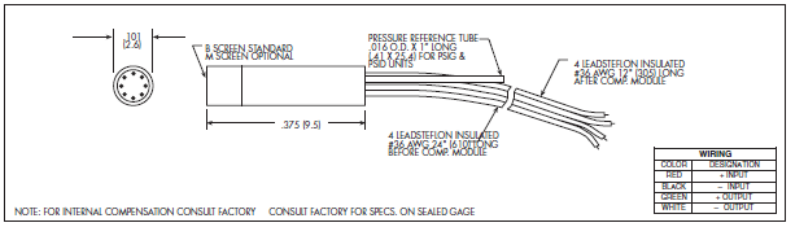
kulite

HIGH TEMPERATURE
MINIATURE IS® PRESSURE TRANSDUCER
XCEL-100 SERIES

- .101" Diameter
- Patented Leadless Technology
- Ideal For Turbine Engine Probes
- Designed For Both Static and Dynamic Measurement
- –65°F To 525°F Temperature Capability

The XCEL-100 design features Kulite's patented leadless technology. This allows for a very rugged package suited for probes, pressure rakes and other similar test set ups. This transducer is well suited for both dynamic and static pressure measurements in benign or harsh environments. Its wide operating temperature range (-65°F to +525°F) makes it ideal for numerous applications in Aerospace and other areas of industry.





WIRING	
COLOR	DESIGNATION
RED	+ INPUT
BLACK	– INPUT
GREEN	+ OUTPUT
WHITE	– OUTPUT

NOTE: FOR INTERNAL COMPENSATION CONSULT FACTORY CONSULT FACTORY FOR SPECS. ON SEALED GAGE

INPUT Pressure Range	0.35 5	1.0 15	1.7 25	3.5 50	7 100	14 200	21 300	35 500	70 BAR 1000 PSI
Operational Mode	Absolute, Gage, Sealed Gage, Differential					Absolute, Sealed Gage			
Over Pressure	2 Times Rated Pressure								
Burst Pressure	3 Times Rated Pressure								
Pressure Media	All Nonconductive, Noncorrosive Liquids or Gases (Most Conductive Liquids and Gases - Please Consult Factory)								
Rated Electrical Excitation	10 VDC/AC								
Maximum Electrical Excitation	15 VDC/AC								
Input Impedance	1000 Ohms (Min.)								
OUTPUT Output Impedance	1000 Ohms (Nom.)								
Full Scale Output (FSO)	100 mV (Nom.)								
Residual Unbalance	± 5 mV (Typ.)								
Combined Non-Linearity, Hysteresis and Repeatability	± 0.1% FSO BFSL (Typ.), ± 0.5% FSO (Max.)								
Resolution	Infinitesimal								
Natural Frequency (KHz) (Typ.)	150	175	240	300	380	550	575	700	1000
Acceleration Sensitivity % FS/g Perpendicular Transverse	$1.5x10^{-3}$ $2.2x10^{-4}$	$1.0x10^{-3}$ $1.4x10^{-4}$	$5.0x10^{-4}$ $6.0x10^{-5}$	$3.0x10^{-4}$ $4.0x10^{-5}$	$1.5x10^{-4}$ $2.0x10^{-5}$	$1.1x10^{-4}$ $1.5x10^{-5}$	$9.0x10^{-5}$ $1.0x10^{-5}$	$6.0x10^{-5}$ $6.0x10^{-6}$	$4.0x10^{-5}$ $4.0x10^{-6}$
Insulation Resistance	100 Megohm Min. @ 50 VDC								
ENVIRONMENTAL Operating Temperature Range	-65°F to +525°F (-55°C to +273°C)								
Compensated Temperature Range	+80°F to +450°F (+25°C to +235°C)								
Thermal Zero Shift	± 1% FS/100°F (Typ.)								
Thermal Sensitivity Shift	± 1% /100°F (Typ.)								
Steady Acceleration and Linear Vibration	1000g Sine								
PHYSICAL Electrical Connection	4 Leads 36 AWG 36" Long								
Weight	.4 Gram (Nom.) Excluding Module and Leads								
Pressure Sensing Principle	Fully Active Four Arm Wheatstone Bridge Dielectrically Isolated Silicon on Silicon Patented Leadless Technology								

Note: Custom pressure ranges, accuracies and mechanical configurations available. Dimensions are in inches. Dimensions in parenthesis are in millimeters.
Continuous development and refinement of our products may result in specification changes without notice - all dimensions nominal. (D)

KULITE SEMICONDUCTOR PRODUCTS, INC. • One Willow Tree Road • Leonia, New Jersey 07605 • Tel: 201 461-0900 • Fax: 201 461-0990 • http://www.kulite.com